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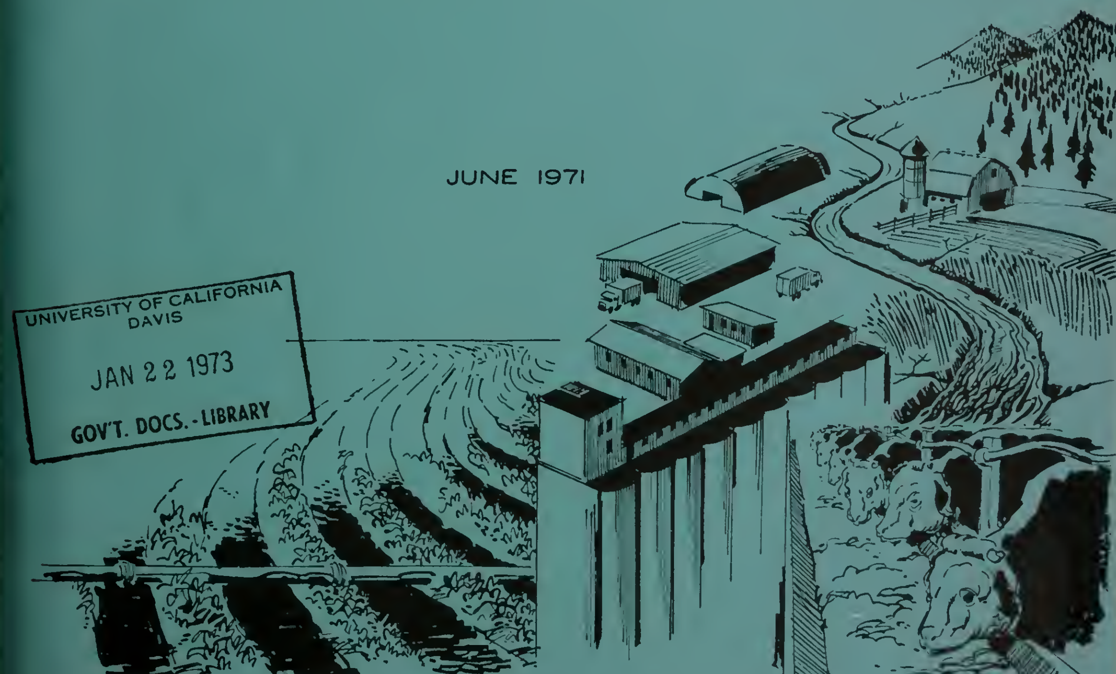
BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE

SAN JOAQUIN VALLEY, CALIFORNIA

TECHNIQUES TO REDUCE NITROGEN IN DRAINAGE EFFLUENT DURING TRANSPORT

JUNE 1971



IRONMENTAL PROTECTION AGENCY ● RESEARCH AND MONITORING

UNITED STATES BUREAU OF RECLAMATION

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE SAN JOAQUIN VALLEY, CALIFORNIA

The Bio-Engineering Aspects of Agricultural Drainage reports describe the results of a unique interagency study of the occurrence of nitrogen and nitrogen removal treatment of subsurface agricultural wastewaters of the San Joaquin Valley, California.

The three principal agencies involved in the study are the Water Quality Office of the Environmental Protection Agency, the U. S. Bureau of Reclamation, and the California Department of Water Resources.

Inquiries pertaining to the Bio-Engineering Aspects of Agricultural Drainage reports should be directed to the author agency, but may be directed to any one of the three principal agencies.

THE REPORTS

It is planned that a series of 12 reports will be issued describing the results of the interagency study.

There will be a summary report covering all phases of the study.

A group of four reports will be prepared on the phase of the study related to predictions of subsurface agricultural wastewater quality -- one report by each of the three agencies, and a summary of the three reports.

Another group of five reports has been prepared on the treatment methods studied and on the biostimulatory testing of the treatment plant effluent. There are four basic reports and a summary of the reports. This report, "REMOVAL OF NITROGEN FROM TILE DRAINAGE", is the summary report.

The other three planned reports will cover (1) techniques to reduce nitrogen during transport or storage, (2) possibilities for reducing nitrogen on the farm, and (3) desalination of subsurface agricultural wastewaters.

BIO-ENGINEERING ASPECTS OF AGRICULTURAL DRAINAGE
SAN JOAQUIN VALLEY, CALIFORNIA

TECHNIQUES TO REDUCE NITROGEN IN DRAINAGE EFFLUENT DURING TRANSPORT

Prepared by the
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REVIEW NOTICE

This report has been reviewed by the Water Quality Office, Environmental Protection Agency and the California Department of Water Resources, and has been approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Water Quality Office, Environmental Protection Agency, or the California Department of Water Resources.

The mention of trade names or commercial products does not constitute endorsement or recommendation for use by either of the two federal agencies or the California Department of Water Resources.

ABSTRACT

Three methods to remove nitrates from the agricultural drainage water from the San Luis Service Area were investigated. One method was a theoretical evaluation of nitrate removal by algae during the transport of the drainage water in the San Luis Canal or during storage in the Kesterson Reservoir. The other methods were designed to promote anaerobic bacterial denitrification in a continuous flow of drainage water. One method used barley straw and the other water grass grown in shallow ponds as the carbon energy source. The barley straw was placed in a trench about 10 feet deep and the nitrate removal rate determined under various flow and detention rates. The water grass was grown in ponds under a continuous flow of water of about 4 to 6 inches depth. Under optimum conditions both methods reduced the nitrate -N concentration of the drainage water from a maximum of about 30 mg/l to less than 2 mg/l. The cost of nitrogen removal by the shallow grass plot systems, the most economical and feasible of these methods, was estimated to be \$6.50 per acre foot or \$20.00 per million gallons.

BACKGROUND

This report is one of a series which presents the findings of intensive interagency investigations of practical means to control the nitrate concentration in subsurface agricultural wastewater prior to its discharge into other water. The primary participants in the program are the Water Quality Office of the Environmental Protection Agency, the United States Bureau of Reclamation, and the California Department of Water Resources, but several other agencies also are cooperating in the program. These three agencies initiated the program because they are responsible for providing a system for disposing of subsurface agricultural wastewater from the San Joaquin Valley of California and protecting water quality in California'a water bodies. Other agencies cooperated in the program by providing particular knowledge pertaining to specific parts of the overall task.

The ultimate need to provide subsurface drainage for large areas of agricultural land in the western and southern San Joaquin Valley has been recognized for some time. In 1954, the Bureau of Reclamation included a drain in its feasibility report of the San Luis Unit. In 1957, the California Department of Water Resources initiated an investigation to assess the extent of salinity and high ground water problems and to develop plans for drainage and export facilities. The Burns-Porter Act, in 1960, authorized San Joaquin Valley drainage facilities as part of the State Water Facilities.

The authorizing legislation for the San Luis Unit of the Bureau of Reclamation's Central Valley Project, Public Law 86-488, passed in June 1960, included drainage facilities to serve project lands. This Act required that the Secretary of Interior either provide for constructing the San Luis Drain to the Delta or receive satisfactory assurance that the State of California would provide a master drain for the San Joaquin Valley that would adequately serve the San Luis Unit.

Investigations by the Bureau of Reclamation and the Department of Water Resources revealed that serious drainage problems already exist and that areas requiring subsurface drainage would probably exceed 1,000,000 acres by the year 2020. Disposal of the drainage into the Sacramento-San Joaquin Delta near Antioch, California, was found to be the least costly alternative plan.

Preliminary data indicated the drainage water would be relatively high in nitrogen. The then Federal Water Quality Administration conducted a study to determine the effect of discharging such drainage water on the quality of water in the San Francisco Bay and Delta. Upon completion of this study in 1967, the Administration's report concluded that the nitrogen content of untreated drainage waters could have significant adverse effects upon the fish and

recreation values of the receiving waters. The report recommended a three-year research program to establish the economical feasibility of nitrate-nitrogen removal.

As a consequence, the three agencies formed the Interagency Agricultural Wastewater Study Group and developed a three-year cooperative research program which assigned specific areas of responsibility to each of the agencies. The scope of the investigation included an inventory of nitrogen conditions in the potential drainage areas, possible control of nitrates at the source, prediction of drainage quality, changes in nitrogen in transit, and methods of nitrogen removal from drain waters including biological-chemical processes and desalination.

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SECTION I

CONCLUSIONS

1 - The two methods, deep trench and the shallow grass ponds, investigated at the San Luis Wasteway are technically feasible and capable of removing nitrates to varying degrees.

2 - The shallow grass pond method, except for a one - or - two month period in the late fall or early winter, was more efficient than the deep trench methods.

3 - The shallow grass pond method offers the potential for costs which are substantially lower than other nitrogen removal treatment processes studied by the Interagency Group, if it can be demonstrated that sustained operations, under field conditions, will yield the desired qualities of effluent.

4 - The cost of treating the projected tile drainage effluent from the San Luis area by the shallow grass pond method, based on information developed in this study, would be approximately $20 per million gallons or $6.50 per acre foot.

5 - Further investigations are required before a full-scale operation of this method should be employed.

SECTION II

RECOMMENDATIONS

The investigations to date indicate that the shallow pond method has a potential for nitrate removal at a reasonable cost therefore it is recommended that further studies be conducted on this method and variations of this method to gain additional data on optimum operating conditions and design criteria. When the San Luis Drain and the Kesterson Reservoir go into operation it is further recommended that a full scale plot be set up in the Reservoir.

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SECTION III

INTRODUCTION

The San Luis Canal-California Aqueduct, a joint Federal and State of California water operation, will import large quantities of water into the westside of the central and southern San Joaquin Valley. This importation of water will permit more intensive surface irrigation of the lands and will reduce the amount of pumping from the groundwater. These factors combined with the relatively slowly permeable and stratified soils will promote the formation of saline, high ground-water in much of the area. A system of on-farm subsurface drains will be required to maintain the groundwater at an acceptable level if land productivity is to be maintained.

To provide an outlet for the farm drain effluent from the San Luis Service Area the United States Bureau of Reclamation has started construction of the San Luis Drain. During the first stage of operation this Drain will terminate at the Kesterson Reservoir. Ultimately the Drain is designed to discharge into the Sacramento-San Joaquin Delta near Antioch. When conditions warrant, the State of California plans to construct a drainage canal to serve the remainder of the Valley which is also planned to discharge into the Delta. The water collected from these subsurface drains and carried by the drainage canals is expected to contain relatively high concentrations of nitrate-nitrogen. Recent studies (1,2) suggest levels of approximately 20 milligrams per liter (NO_3-N) and this may have a potential for causing undesirable algae blooms in the receiving water of the Delta.

SECTION IV

OBJECTIVES

An objective of the project was to determine changes in N-forms during transit to treatment systems. One of the original plans was to evaluate the change in N in drainage waters as they moved through an operating canal system. A search was made in areas which have climatological, soil and irrigation conditions somewhat similar to those in the San Joaquin Valley. A check of the nitrogen concentration in the drainage systems in the Wellton-Mohawk, Gila and Imperial Valley service areas, did not reveal any systems which had quantities of nitrogen sufficiently high to give any significant evaluation.

To satisfactorily duplicate the anticipated nitrate levels of the San Luis Drain water would involve prohibitive costs for addition of nitrates to a system of similar size. The reduction to experimental scale would result in smaller costs for nitrate addition; however, the biological environment might then be poorly duplicated and the results would be of questionable value. Consequently measurements of this type, were postponed until sections of the San Luis Drain are completed. At that time, any changes in nitrogen in the drainage water from the San Luis service area during transport from Westlands Water District to the Kesterson Reservoir can be monitored.

Therefore, in lieu of the study of changes in transport, the emphasis of this project was shifted to determine what changes could be effected in the drainage waters by using facilities similar to the designed transport and storage system facilities and the use of agricultural waste products.

Two separate studies were made to accomplish these objectives. One was a plan to combine nutrient removal by promoting algae growth within the transport system, the San Luis Drain and the Kesterson Reservoir. This method of treatment was proposed by a team from the Firebaugh Waste Water Treatment Center (3). The evaluation of this proposal was based primarily on theoretical calculations rather than on an experimental model. The second study was concerned with nitrate removal in the transportation system by the denitrification process. This later study was in two phases, one utilized an elongated,relatively deep pond somewhat similar to a section of the San Luis Drain and the other a broad relatively shallow pond, similar to a cell of Kesterson Reservoir.

SECTION V

METHODS, MATERIALS AND RESULTS

This section describes the method and materials used in the study of techniques to reduce nitrogen concentrations in drainage effluent during transport or storage and discusses the result of the findings of the investigations.

Nutrient Removal by Algal Growth within the Transport System

A study was prepared by Joel C. Goldman, James F. Arthur and others (3) on the possibility of using the San Luis Drainage transport and storage systems as a means to remove nutrients by the growth and harvesting of algae in these facilities. The plan was proposed on the premise that, under favorable environmental conditions, there will be a natural growth of algae within the San Luis Drain and Kesterson Reservoir, and that if, maximum algal growth was promoted it could serve as a dual treatment - transport system. The study was based primarily on basic assumptions and theoretical calculations rather than on an experimental model.

Some of the criteria, particularly the projected flow of the San Luis Drain and the size of Kesterson Reservoir have been changed since the report was published, however, the basic theories, calculations and conclusions in the study remain valid.

Calculations in the study indicated that the biomass required to remove 90 percent of the estimated 25 mg/l of nitrogen in the drainage water would be 280 mg/l. It was postulated that a portion of this quantity that could be grown in the Drain or the Reservoir would reduce the land requirements for nutrient removal in the treatment facilities thereby reducing the total nitrogen removal costs. The study suggested that any action which could reduce the acreage requirements in the Antioch area where land values are high would be especially effective in reducing the overall project costs.

Utilizing the San Luis Drain

The studies indicated that the actual algal concentrations that will be in the Drain are almost impossible to predict. When flow in the San Luis Drain reaches its projected capacity it will have a surface area of about 770 acres and a mean detention time of 6.3 days. Algal cells will multiply rapidly, doubling about ½ to 1 times per day, thus there would probably be 4 or 5 doublings during transit. Based on Dr. William Oswald's calculations and his most conservative estimate of an original concentration of 1 mg/l of algae and 4 doublings during transit to the Delta, then 16 mg/l of algae would be present at discharge. His less conservative estimate assumed that the water started with 2 mg/l of algae and there were 5 doublings, then the final concentration would be 64 mg/l. Theoretically,

based upon Dr. Oswald's calculations, the Drain has the capability of supporting about 100 mg/l of algae considering light limitations only. Shallow ponding would be required to attain any further increment of growth.

An approximation of the amount of nitrogen removed from the drainage water through the growth of the algae can be calculated by making several assumptions:

1. Final algal concentration = 16 to 64 mg/l.

2. Nitrogen content of algal cells = 8-10 percent (use 8 percent)

3. Total nitrogen concentration in drainage water = 20-25 mg/l (use 25 mg/l)

Thus the amount of nitrogen removed from drainage water and converted into algal cell material can be calculated as follows:

16 mg/l X 0.08 = 1.28 mg/l (minimum estimate)

64 mg/l X 0.08 = 5.12 mg/l (maximum estimate)

or approximately:

$\frac{1.28}{25}$ X 100 = 5 percent (minimum estimate)

$\frac{5.12}{25}$ X 100 = 20 percent (maximum estimate)

of the incoming nitrogen will be removed.

Since the amount of nitrogen removed will be directly proportional to the concentration level of algae, nitrogen removal could be increased by increased algal growth in the Drain. Methods to gain increased growth would be to seed the Drain to get as high an initial algal concentration as practical and then encourage as many doublings as possible to occur during transit. Doublings could be increased by modifying the Drain to create greater turbulence and effective surface area by placing baffles in the Drain, aerating or adding gases.

Utilizing Kesterson Reservoir

The study points out that the Kesterson Reservoir, an integral part of the Drain system, could be utilized as a combined reservoir and algae growth treatment plant. If the algae growth system was designed for the optimum operating depth and a storage capacity depth of two feet, the system would have the capability for essentially 100 percent treatment and still serve as an emergency storage reservoir.

This system could be designed to minimize the power required for mixing by taking advantage of the natural land slope to the north. The design would entail a series of equally spaced channels running along the length of the reservoir in the direction of the slope. If it was necessary, pumps could be used to produce the required initial mixing velocities. Any desired detention time could be maintained by recirculating a portion of the effluent.

Research at Firebaugh indicates that both the "bacterial denitrification" and the algae "growth and harvest" are technically feasible, therefore, a combination of the two systems in a series type operation might give the best results. The algae growth and harvest could take place in the Drain and Kesterson Reservoir followed by anaerobic filters for final treatment.

Nutrient Removal by Field Denitrification Processes

The denitrification studies were based upon the principle that in the presence of an adequate concentration of a degradable organic material and restricted aeration bacteria will utilize the available dissolved oxygen. Then, in the absence or near absence of oxygen, denitrification is accomplished by facultative anaerobic bacteria which are capable of using NO_3 in place of oxygen as a hydrogen acceptor. The reactions which take place in this reduction process are subject to a certain amount of controversy and speculation. Nightingale (4) suggests a basic simplified multi-step reaction pathway as follows:

$$\mathrm{N}\begin{array}{l}\mathrm{O^-}\\ \mathrm{O}\\ \mathrm{O}\end{array} + 2\mathrm{H} \rightarrow \mathrm{N}\begin{array}{l}\mathrm{O}\\ \\ \mathrm{O}\end{array} + 2\mathrm{H_2O} \xrightarrow{6\mathrm{H}} \begin{array}{c}\mathrm{N{-}OH}\\ \Vert\\ \mathrm{N{-}OH}\end{array} + 2\mathrm{H_2O} \longrightarrow \begin{array}{c}\mathrm{N}\\ \equiv\\ \mathrm{N}\end{array} \mathrm{O} + \mathrm{H_2O} \xrightarrow{2\mathrm{H}} \begin{array}{c}\mathrm{N}\\ \equiv\\ \mathrm{N}\end{array} + \mathrm{H_2O}$$

Nitrate Nitrite Hyponitrite Nitrous Oxide Nitrogen Gas

The denitrification studies were carried out in two phases. One, at the Firebaugh Center, had the main responsibility for anaerobic denitrification with methanol. The other, conducted near the San Luis Wasteway, main interest was denitrification with natural carbon sources. In the latter projects, barley straw was used as the carbon energy source in the deep trench study and water grass grown in place was the source in the shallow pond study.

The plots were set up on Bureau of Reclamation owned land near the San Luis Wasteway approximately 5 miles northwest of Los Banos. The soils in the area are classified as Orestimba clay loam (5). These soils are developed on alluvial material derived from the softly consolidated calcareous, gypsiferous sandstones and shales of the Coast Range Mountains. They are moderately to strongly saline with slight to moderate compaction in the subsoil. Plans of the systems are shown in Figure 1.

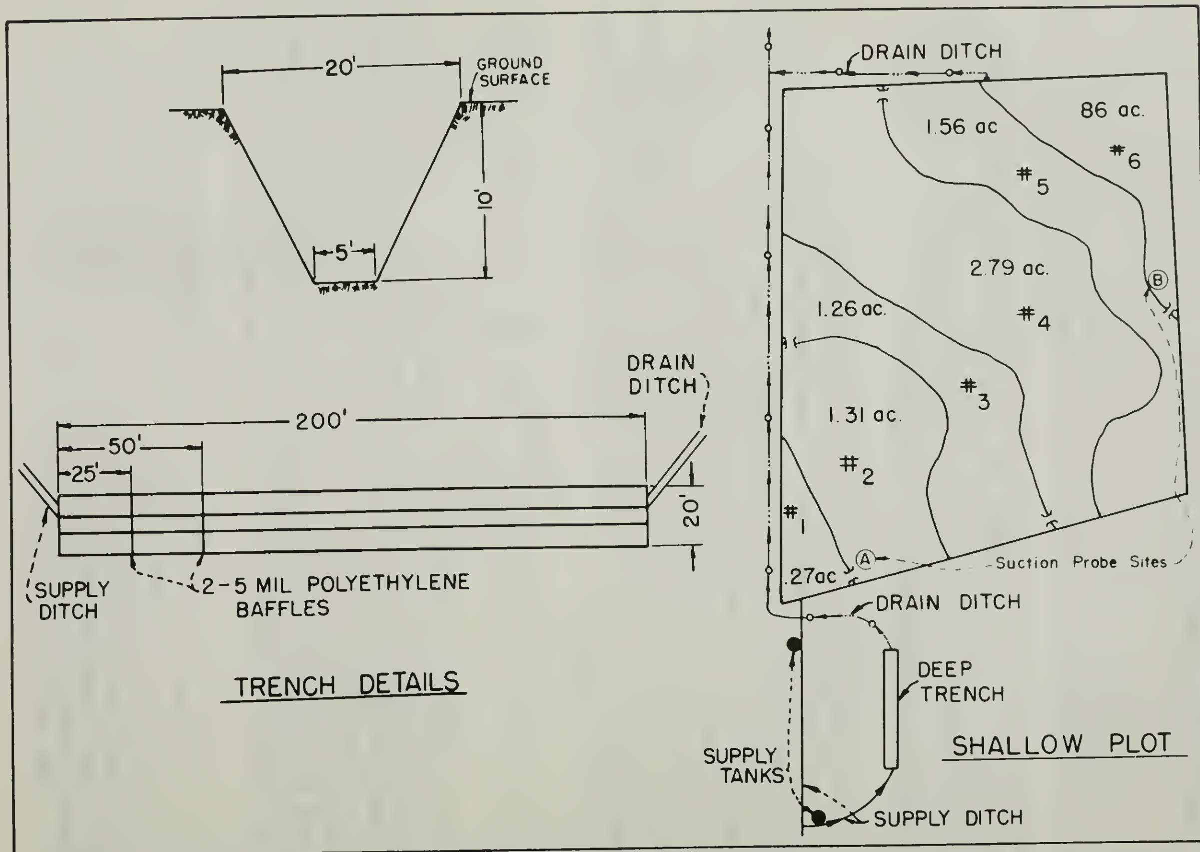


FIG. 1 - PLAN OF DENITRIFICATION PLOTS

The water supply for the investigations was pumped from the San Luis Wasteway which contains a mixture of groundwater and imported Delta-Mendota Canal water. The total quantity and the distribution of various ions in the water varied with the season. A representative analysis of the water is listed in Table 1.

Table 1
Chemical Analysis of Supply Water

pH	conductivity $ECX10^6$	Ca	Mg	Na	NO_3	CO_3	HCO_3	Cl	SO_4	T.D.S.
							mg/l			
7.6	1400	37	42	172	4	0	378	203	48	884

The nitrate concentration of the supply water normally was less than 5 mg/l. Because of this low nitrogen level, for purposes of this study, it was necessary to supplement the water with nitrates. This was accomplished by dissolving calcium nitrate in a large supply tank and then running this through a small balancing tank into the supply ditch. It was planned to maintain a NO_3-N level of approximately 9 mg/l in the deep trench and 14 mg/l in the shallow ponds. However, maintaining this desired level proved to be difficult due primarily to clogging of the outflow valve by precipitated salts and foreign matter.

Sample Collection and Analytical Techniques

Samples were collected from the plots and analyzed by the methods listed below:

Analysis	Method
Nitrates	Specific Ion Meter (6) and/or Brucine (7)
Total Nitrogen (Kjeldahl)	Micro Kjeldahl
Ammonia	Distillation
Organic Nitrogen	Micro Kjeldahl
Dissolved Oxygen	Winkler (Hach)
pH	Glass Electrode
Electrical Conductivity	Conductivity Bridge
Mineral Constituents	Laboratory Procedures (8)

In addition to the chemical analysis the temperatures were monitored. The rate of inflow and outflow was measured by a Parshall flume equipped with a continuous stage water recorder.

Deep Trench Study

This investigation was conducted in a trench designed to simulate a section of the San Luis Canal.

Methods and Material A trench approximately 10 feet deep, 20 feet wide at the top and 200 feet long was excavated. The trench was filled with drainage water supplemented with calcium nitrate and covered with a layer of barley straw approximately six inches thick. Additional straw was added periodically as open spots appeared in the straw cover. The barley straw was the degradable organic material used as the energy source for the bacteria.

The system was planned to operate as simply as possible with water entering the trench from a supply ditch flowing through the straw covered trench. However soon after the start of the experiment it became obvious that the inflow water was short-circuiting through the trench without completely displacing the water in the trench. Two five mil polyethylene plastic curtains were suspended across the trench 25 feet and 50 feet downstream from the inlet to alleviate this problem. These curtains acted as baffles to force the water flow downward. Although there were still stagnant areas in the system, especially near the botton, the baffles did increase the percentage of the water that was displaced.

A dissolved oxygen sampler was used to collect samples from the middle of the trench 2 feet below the water surface at the inlet and outlet and at stations 10, 25, 50, 60, 100 and 175 feet downstream from the inlet. At the 175-foot station, near the outlets of the trench, samples also were collected at depths of 4 and 8 feet. All samples were analyzed for nitrates, dissolved oxygen, pH and electrical conductivity.

In addition some of the samples were analyzed for nitrites, ammonia and organic nitrogen.

Results - Samples were collected from the trench between October 1967 and July 1968. The nitrate concentrations of the drainage water at sampling points and for various dates as the water moved through the trench are listed in Table 2. The variability of the nitrate concentration of the supply water at the inlet was due to fluctuations in the flow from the supplemental nitrate supply system. The amount of nitrate removal ranged from almost complete removal of the nitrate to less than 50 percent. Although the removal rate varied widely, the reduction that did occur normally took place within the first 50 foot lengths of the trench.

The nitrate concentration of the supply and the discharge waters and the temperature of the discharge water for data collected between October 1967 and July 1968 are shown in Figure 2. Although most of the nitrate reduction took place within the first 50 feet, the detention times listed below were based on the water flowing through the entire reach of the trench. The detention times used in this study were theoretical times based on the volume of the trench divided by the influent flow rates. These calculations neglected possible short-circuiting and stagnant zones in the

Table 2

Nitrate Concentration, Dissolved Oxygen and Detention Time of Water
In Deep Pond Studies at Several Sampling Points

Date	Inlet		10'			25'			50'			100'			175'			Outlet(200')		
	NO_3-N mg/l	DO	NO_3-N mg/l	DO	DT Days	NO_3-N mg/l	DO	DT Days	NO_3-N mg/l	DO	DT Days	NO_3-N mg/l	DO	DT Days	NO_3-N mg/l	DO	DT Days	NO_3-N mg/l	DO	DT Days
10/18/67	7	7.2	1	0	.30	1	0	.75	1	0	1.50	1	0	3.0	1	0	5.25	1	0	6.0
10/26/67	6	7.4	1	0	.30	1	0	.75	1	0	1.50	1	0	3.0	1	0	5.25	1	0	6.0
10/31/67	8	6.6	11	0	.30	11	0	.75	1	0	1.50	1	0	3.0	1	0	5.25	1	0	6.0
11/07/67	5	7.7	1	0	.18	1	0	.44	1	0	.88	1	0	1.75	1	0	3.06	1	0	3.50
11/13/67	7	8.2	5	2.4	.18	5	3.2	.44	5	1.8	.88	4	0.8	1.75	3	0	3.06	4	0	3.50
11/16/67	7	8.6	3	2.6	.18	3	3.4	.44	3	5.0	.88	2	3.0	1.75	1		3.06	2	0.2	3.50
11/21/67	7	8.6	2	0	.18	1	0	.44	1	0	.88	1	0	1.75	1	0	3.06	1	0	3.50
11/29/67	9	8.8	3	1.0	.10	2	0.6	.25	2	0	.50	2	0	1.00	2	0	1.75	-	.8	2.00
12/11/67	6	9.6	5	5.0	.17	6	7.2	.41	5	5.0	.82	3	1.6	1.65	1	1.0	2.88	2	.8	3.3
12/21/67	10	6.0	7	3.4	.17	8	5.4	.41	9	5.4	.82	9	4.4	1.65	-	-	2.88	9	5.0	3.3
12/27/67	7	7.0	5	5.2	.17	7	5.2	.41	6	1.8	.82	5	2.8	1.65	3	2.0	2.88	5	2.6	3.3
1/17/68	10	8.6	6	1.2	.17	5	1.0	.41	6	2.0	.82	5	2.4	1.65	5	-	2.88	5	3.8	3.3
1/24/68	8	8.6	7	2.8	.17	4	0	.41	4	0.8	.82	4	1.8	1.65	4	5.4	2.88	4	6.2	3.3
1/31/68	14	8.0	7	2.0	.17	3	0	.41	2	.6	.82	2	.6	1.65	4	2.4	2.88	5	6.0	3.3
2/07/68	11	7.6	6	0	.17	3	1.2	.41	3	4.6	.82	3	5.0	1.65	2	5.0	2.88	2	7.2	3.3
2/15/68	9	9.6	5	2.4	.17	2	0	.41	1	0	.82	1	0	1.65	1	0	2.88	1	0	3.3
2/28/68	7	6.8	6	2.0	.17	4	3.6	.41	1	0	.82	1	0	1.65	1	0	2.88	1	0	3.3
3/06/68	9	8.0	9	1.4	.17	5	2.2	.41	1	0	.82	1	0	1.65	1	0	2.88	1	0	3.3
3/14/68	7	8.4	7	6.6	.10	5	5.0	.25	4	5.6	.50	4	5.4	1.0	3	6.0	1.75	3	6.6	2.0
3/21/68	7	8.0	7	2.6	.10	5	.4	.25	2	0.2	.50	3	3.0	1.0	3	3.4	1.75	3	4.0	2.0
3/27/68	9	8.4	8	6.0	.10	5	2.2	.25	4	2.8	.50	2	2.6	1.0	2	4.0	1.75	2	3.0	2.0
4/03/68	8	8.0	6	1.0	.10	5	-	.25	3	2.4	.50	2	2.8	1.0	2	2.8	1.75	2	2.8	2.0
4/24/68	9	8.4	9	.8	.17	5	-	.41	7	4.4	.82	6	6.6	1.65	6	6.6	2.88	6	6.8	3.3
5/08/68	7	8.8	7	5.4	.17	5	.8	.41	6	2.4	.82	4	3.8	1.65	4	4.8	2.88	4	5.2	3.3
5/15/68	7	8.0	6	3.4	.22	7	3.6	.56	6	5.4	1.12	5	5.0	2.25	5	5.4	3.93	5	5.0	4.5
5/22/68	16	8.4	12	-	.22	13	.4	.56	11	2.4	1.12	8	2.6	2.25	7	5.6	3.93	7	6.8	4.5
5/27/68	14	9.0	17	.8	.22	14	1.0	.56	10	3.8	1.12	9	7.0	2.25	8	6.8	3.93	9	7.6	4.5
6/05/68	22	6.0	7	0	.22	5	.6	.56	5	1.2	1.12	5	3.0	2.25	5	4.6	3.93	6	5.6	4.5

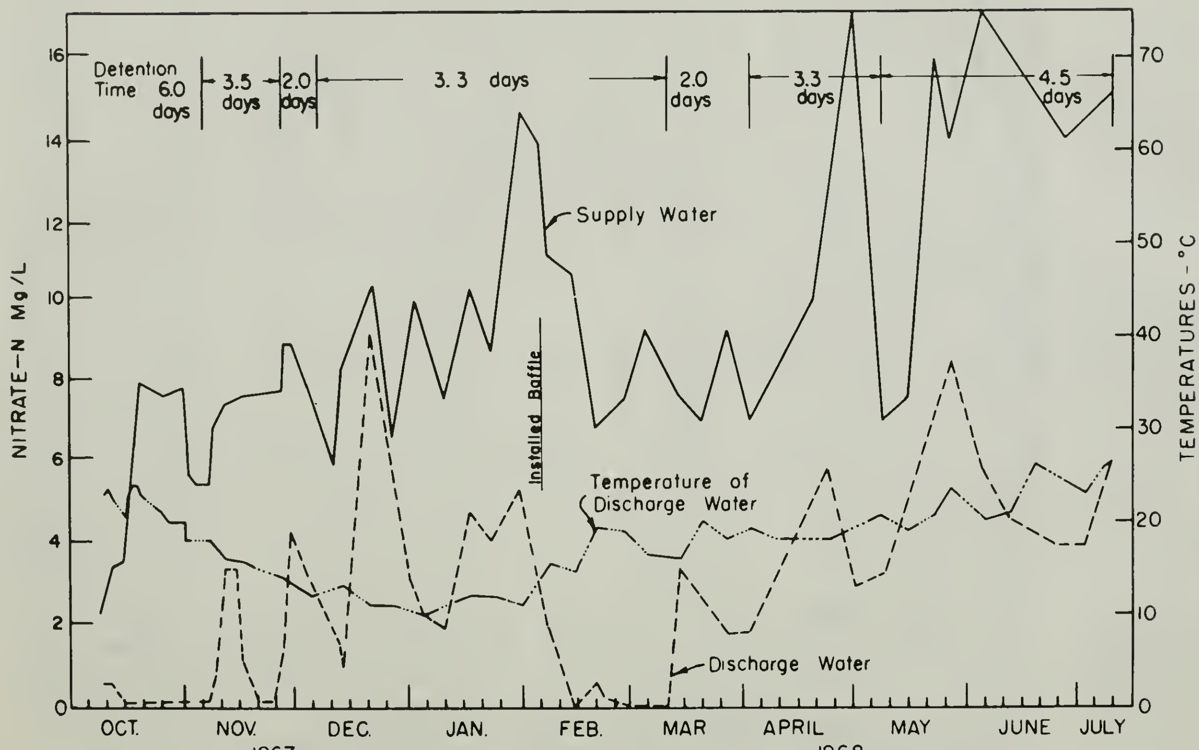


FIG. 2-DEEP TRENCH —NITRATE CONCENTRATIONS AND TEMPERATURES

trench, therefore, the true values are probably less than those listed here. Table 2 lists the detention times and the dissolved oxygen concentrations at the various sampling stations in the trench for several dates during the study.

During the first six months of the study the NO_3-N concentration of the supply water normally ranged between 5 and 9 mg/l with an average concentration of about 8 mg/l. During the last three months the NO_3-N concentration rate was increased to an average of about 14 mg/l.

During the first month of the experiment a detention time of 5.9 days was maintained. At this rate the nitrate nitrogen concentration in the discharge water was reduced to less than 1 mg/l. When the detention was reduced to 3.5 days the NO_3-N concentration in the discharge water was about 3 mg/l or about 57 percent of the concentration of the supply water. When a fresh supply of straw was added to the trench the NO_3-N in the discharge water was reduced to zero with no change in the 3.5 day detention time.

A further decrease of the detention time to 2 days resulted in a rise in the NO_3-N content of the discharge water to about 4 mg/l. The detention time was increased to 3.3 days but no appreciable change in the nitrate content of the discharge water was noted.

It was concluded that the reason for the lack of response to the change was that the effective detention time was being reduced by the short-circuiting of the water and the disappearance of the more readily available energy source in the straw. The system was redesigned to overcome this problem by installing the two baffles and adding more straw.

After the system was changed and with approximately the same detention time, 3.3 days, the NO_3-N concentration in the discharge water was reduced to less than 1 mg/l. The conditions were kept constant and this near complete reduction rate was maintained for about a month.

When the detention time was again reduced to 2.0 days the nitrate concentration in the discharge water increased. Even though the detention time was later increased to 4.5 days, the nitrate reduction rate remained at about 40 percent.

It is postulated that the principle reason for the lower reduction rate during the later part of the study was the lack of an adequate, available organic energy source to maintain the bacterial population required for removal of all the nitrates in the system. Fresh straw was added routinely at the rate of about 300 pounds per week to maintain a solid cover over the water. This quantity apparently did not replenish the organic carbon source as rapidly as it was used. In part this problem was the result of wind blown dust deposited in the straw-water mixture. As this dust became mixed with the other

components a soil-water-straw mixture was formed on the surface of the water in the trench which was relatively unusable as an energy source for the bacteria. This material floated on or near the water surface and prevented much of the fresh straw from coming in contact with the water in the trench.

The dissolved oxygen content of the supply water and the discharge water at various dates during the period of the study are plotted in Figure 3. The dissolved oxygen content of the supply water, normally sampled near midday, ranged from 6 to 10 mg/l. The content of the discharge water ranged from zero to 7 mg/l. There was a very close correlation between the dissolved oxygen content reduction and amount of nitrate reduction. During those periods when the nitrate levels were reduced to near zero the dissolved oxygen contents were also near zero. This correlation is to be expected, however, it is somewhat surprising that there was at least partial denitrification although the dissolved oxygen apparently was not reduced to zero. It was assumed that this denitrification occurred in some local areas within the system where there was complete or near anaerobic conditions which were not detected in our sampling program.

Although no determinations were made, at times it was evident from the odor of hydrogen sulfide that sulfate reduction was occurring. As the presence of nitrates inhibits sulfate reduction the appearance of hydrogen sulfide in the trench would indicate the removal of most or all of the nitrates from the water (9). Several times during the investigation the hydrogen sulfide odor plus those from some of the other decomposition products of the straw caused a rather unpleasant environment around the plot area.

A number of nitrite and ammonia analyses were made of the supply and discharge water to determine if there was a build up of either of these nitrogen forms in the water in the trench during the denitrification process. Table 3 lists the quantities of NO_3-N, NO_2-N and NH_3-N found in the supply and discharge water at various times during the experiment. Also included are the pH, electrical conductivity and temperature of the water at the time it was sampled. The NO_2-N did not increase significantly except during the coldest weather. During this cold period the increase in nitrite accounted for only about 4% of the nitrate reduction. Most data show that there was a reduction in the ammonia. One reason for the relatively high concentration of ammonia in the supply water is that there was a small percentage of this salt mixed with the $Ca(NO_3)_2$ which was used as the nitrate source to supplement the native nitrogen in the water.

There were several factors such as the energy source, detention time and temperature which affected the reduction rate of the nitrates and dissolved oxygen. These factors are inter-related or are masked sufficiently to prevent the analyses made in this study from showing the relative contribution of each.

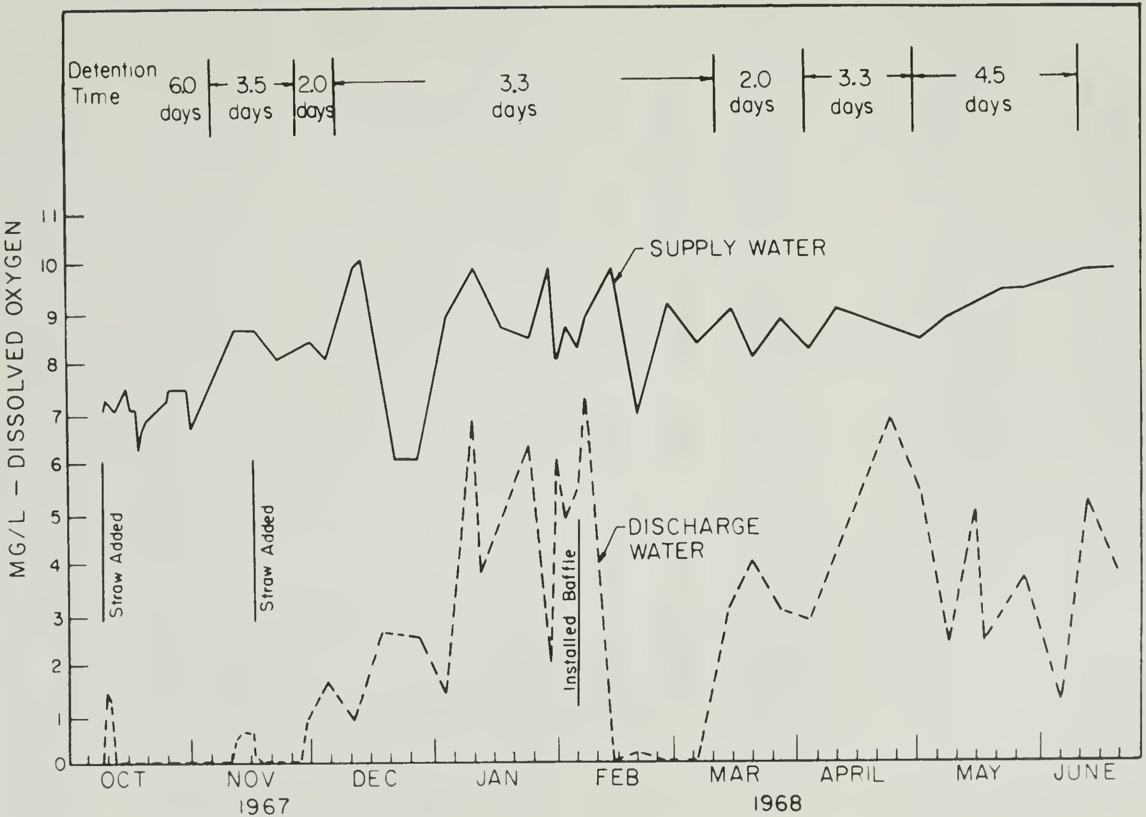


FIG 3 - DEEP TRENCH - DISSOLVED OXYGEN

Table 3

The Concentrations of the Various Nitrogen Forms, pH, Electrical Conductivity and Temperature of the Supply and Discharge Water, at Various Times During the Deep Trench Experiment.

		N-Form			pH	EC	Temp.
		NO_3-N	NO_2-N	NH_3-N			
		mg/l				mmhos	°C
10-21-67	Supply	14.5	0.3	0.19	7.4	0.55	23
"	Discharge	0	0.1	0.17	6.9	0.69	21
11-13-67	Supply	11.2	-	0.57	7.3	0.63	17
"	Discharge	2.0	-	0.55	7.6	0.65	16
1-03-68	Supply	10.0	0.4	0.38	7.9	1.70	10
"	Discharge	2.3	0.7	0.48	7.9	1.60	10
3-06-68	Supply	9.6	0.05	0.90	7.6	1.90	17
"	Discharge	.1	0.00	0.48	7.4	1.90	17
5-01-68	Supply	18.0	0.08	1.1	7.8	1.45	22
"	Discharge	3.0	0.29	0.06	8.0	1.50	22
7-10-68	Supply	15.0	0.1	1.15	8.3	1.30	30
"	Discharge	6.2	0.4	0.67	8.3	1.20	27

Detention Time - The calculated theoretical detention time of the entire system for this study ranged from 2 to 6 days. Some generalizations can be made about the effect of detention time on nitrate removal from this system. First, when there were no other limiting parameters almost complete reduction of the nitrates was obtained with a detention time of 3.3 days. With detention times of less than 3.3 days, there was never more than 80 percent reduction of the nitrates.

Temperature - The temperature of the discharge water ranged from 27°C in July to a minimum of 8°C in January. Other studies (7) have indicated that 16°C may be the lower limit for efficient denitrification. This experiment, however, did not show any correlation between temperature and nitrate reduction or if there was an effect it was masked by other factors.

Energy Source Requirements - The theoretical straw requirement can be calculated using a formula derived from work by P. L. McCarty (10). A quantity of organic waste with an oxygen equivalent (Oe) of 2.86 pounds would be required to convert one pound of nitrate-nitrogen into nitrogen gas. However, in the biological

process, a minimum of 25 percent of the added organic material, is used by micro-organisms for cell synthesis and is therefore unavailable for denitrification. Where the organic source is not easily broken down, such as the barley straw used in this study, probably no more than 50 percent of the material will be available for denitrification. Thus in practice an organic waste with an Oe of 2.86/.50 or 5.72 pounds is required per pound of nitrate-N. In addition, some organic material must be added to create the anaerobic conditions required for denitrification. This requires about 1.5 pounds of Oe per pound of dissolved oxygen (DO) in the incoming drainage water. In summary the organic oxygen equivalent required (O_r) for denitrification can be expressed as follows:

$$O_r = 5.72\ (NO_3\text{-}N) + 1.5\ (DO)$$

If we assume that there will be 20 milligrams per liter of NO_3-N and 8 parts per million of dissolved oxygen in the drainage water theoretical barley straw requirement for denitrification of this water can be calculated from the above formula as follows:

$$O_r = 5.72\ (\text{pounds of } NO_3\text{-N per AF}) + 1.5\ (\text{pounds of DO per AF})$$

$$O_r = 5.72 \times 54.4 + 1.5 \times 21.7 = 343 \text{ pounds per acre-foot}$$

In a like manner the theoretical barley straw requirement for the pond study can be calculated from the above formula. If we assume that the average NO_3-N concentration was 10 mg/l and the dissolved oxygen content of the water was 8 parts per million the calculations are as follows:

$$O_r = 5.72 \times 22.7 + 1.5 \times 21.7$$

$$= 153 \text{ pounds per acre foot}$$

Using this quantity and the various flow rates during the study period the theoretical daily straw requirement ranged from 41 pounds for the 60 gpm flow and the 2 days detention time to approximately 14 pounds for the 20 gpm and the 6 days detention time. The straw requirements for all of the flow rates and detention times are listed in Table 4. According to these calculations the amount of straw, about 50 pounds per day, actually added to the trench should have been more than adequate to provide energy for complete denitrification of the system. That complete removal did not always take place can probably be attributed to the fact that a readily decomposable form of the straw did not come into the contact area because of the mat of soil and straw floating on the water surface.

Electrical Conductivity - The concentration of total dissolved solids as measured by the electrical conductivity of the

water varied during the season from about 300 to 2900 micromhos and was primarily dependent upon the concentration of the supply water rather than any variation as a result of changes within the system. The low concentrations were during the periods of large water releases from the Delta-Mendota Canal into the wasteway and the high concentrations were during periods when all the water in the wasteway was from seepage. Although there were evapotranspiration losses they were not large enough to be measured by the conductivity method used in this study.

Table 4

Flow rates, detention times and straw requirements of deep pond.

Flow GPM	Detention Time Days	Straw Requirement lbs/day @ 10 mg/l NO_3-N
60	2.0	41
36	3.3	
		25
34	3.5	23
30	4.0	20
20	6.0	14

Grass Plot Study

The shallow pond investigations were made on an 8.3 acre plot designed to simulate a section that could be incorporated into the Kesterson Reservoir.

Methods and Materials - The plot was rough leveled, bordered and checked at 0.3 foot contour intervals. A layout of the plot is shown in Figure 1.

Water grass, Echinochloa crusgalli, was planted in the plot at the beginning of the study. The grass was to be the carbon energy source for the denitrification process. The first year it was mowed and left in the field. The mowing did not appear to increase the denitrification rate therefore the practice was discontinued.

The water source for this study was the same as that for the deep trench. Supplemental nitrate was added to the supply water in the manner detailed in the previous study. Sodium nitrate rather than calcium nitrate was used as the nitrate source during a part of the study in an attempt to reduce the percolation losses from the plot.

During the greater part of the investigation the plans were to maintain the nitrate -N levels at about 16 mg/l, however, due to variations in the water and supplemental nitrate-N flows the actual concentrations ranged from about 7 to 70 mg/l. In order to evaluate the nitrate reduction rate of water of higher nitrate -N concentration the levels were increased to about 50 mg/l for about 32 days between April 6 and May 8, 1970.

A continuous flow of water through the plot was maintained with an average depth of approximately six inches. The rate of flow of the water was monitored with Parshall flumes as it entered and left the plot. The maximum flow to the plot was limited by the size and gradient of the supply ditch and because of this the average depth of water was not varied. This flow, approximately 400 gallons per minute, was maintained throughout most of the study. As the water moved through the plot there was a reduction in flow due to evapotranspiration, seepage, and percolation losses. These losses were assumed to be constant through the plot and were taken into consideration in calculating the detention times. The outflow varied from about 30 gallons per minute during the peak evapotranspiration period in the summer to about 140 gallons per minute during the minimum evapotranspiration period in the winter. The inflow rates and the theoretical detention time for each check during representative periods in the summer and winter are listed in Table 5.

Results - The concentrations of the nitrates in the water at the inlet of the plot, the outlets of checks 2 and 4, and the outlet of the plot are graphed in Figures 4 and 5. The data show that as the water moved through the plot there was a reduction in the nitrate concentration. This reduction continued until it reached the outlet of check 4, after this point generally there was no significant change. During the study the amount of nitrate removal varied from almost complete reduction to only about 50 percent reduction. The maximum nitrate -N removal occurred in the summer and early fall months when there was maximum grass growth and during the late winter months and spring after the grass had died back, as a result of killing frosts and had fallen into the water. The least reduction occurred during the months of November and December.

The nitrate -N concentration during the maximum reduction period was reduced from the average 16 mg/l to less than 2 mg/l. During the periods of lesser reduction the concentration at the outlet at times ranged up to about 4 mg/l of nitrate -N. The reduction pattern and rates were relatively consistent for the two years that the tests were conducted.

The main emphasis of the study was placed on the removal of nitrate, the principle nitrogen form in the drainage water, however, any treatment system must be concerned with the removal of the total nitrogen content of the water. The concentration of other nitrogen

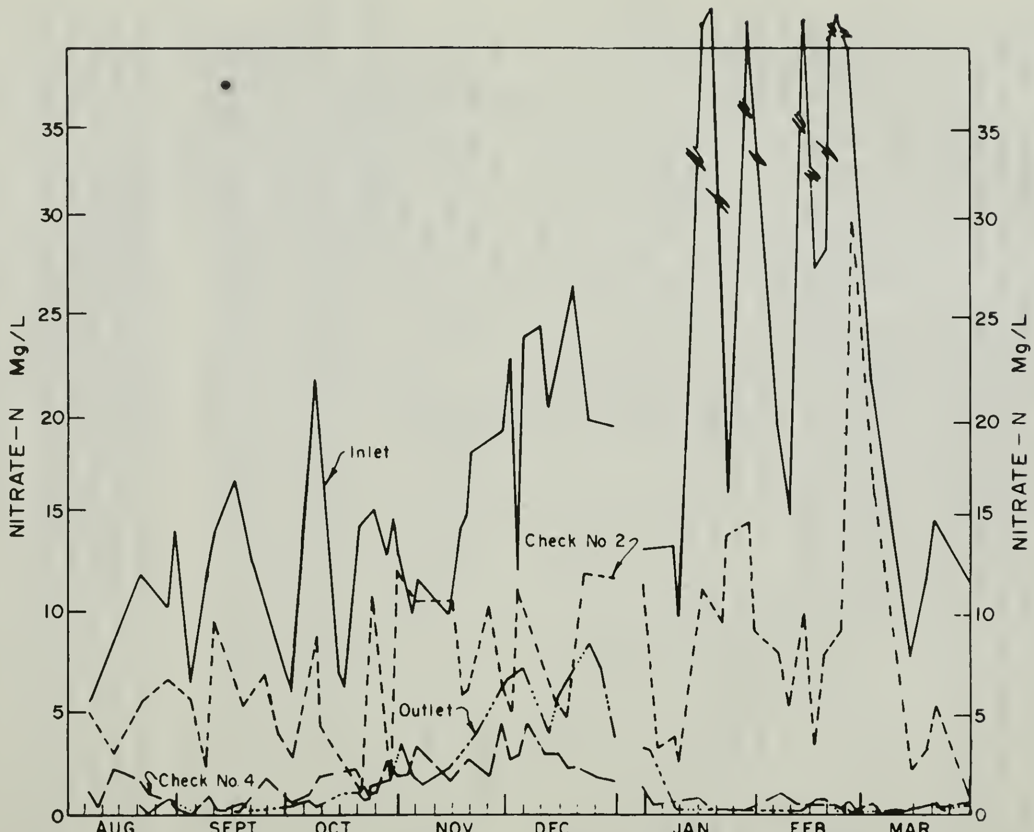


FIG 4 - GRASS PLOT - NITRATE CONCENTRATION - 1968-1969

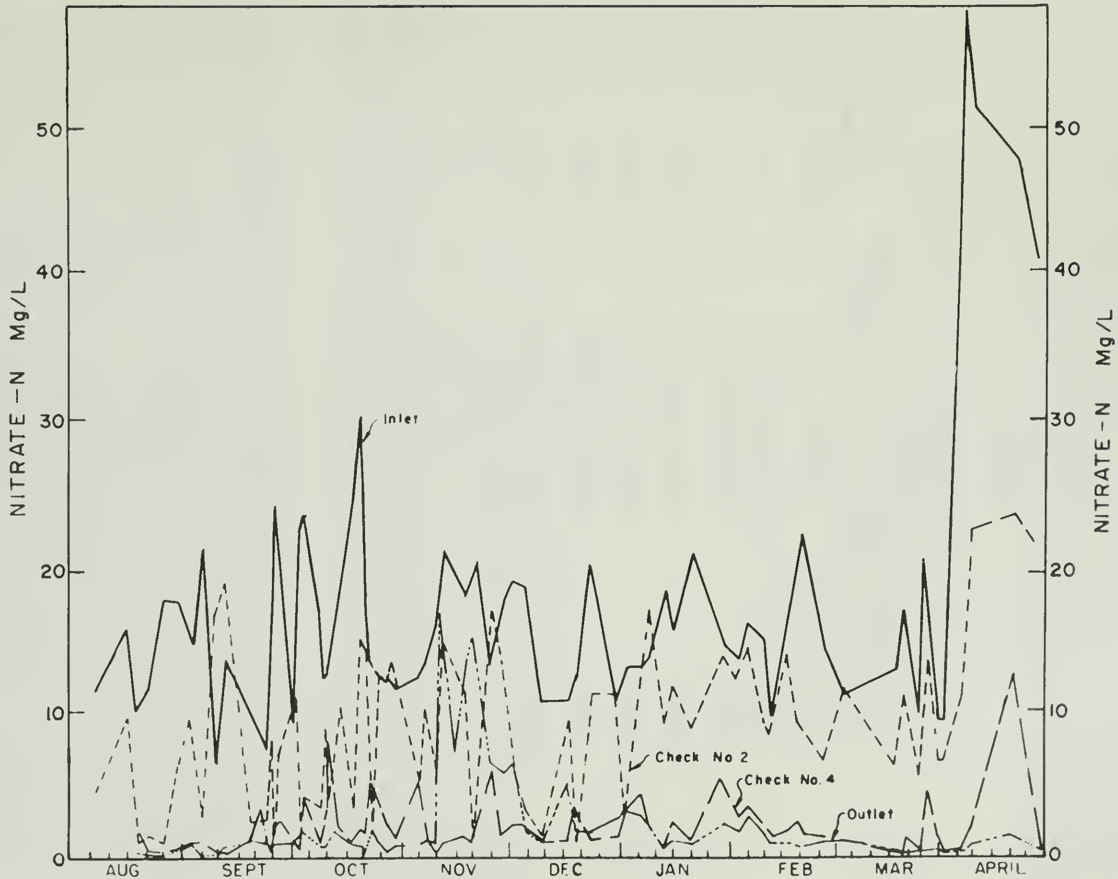


FIG 5 - GRASS PLOT - NITRATE CONCENTRATION - 1969-1970

forms, nitrite, ammonia and organic N were generally low in both the influent and effluent waters. However, there were periods during the winter months when there was evidence, as noted in Table 9, that the total nitrogen content, especially the organic -N in the effluent was greater than the allowable maximum nitrogen discharge rate for the Delta of 2 mg/l.

Table 5

Calculated Inflow Rates and Theoretical Detention Times of the Various Checks in the Grass Plot

Check No.	Area Acres	Ave. Flow Rates GPM		Detention Time (Days)			
				Per Check		Accumulative	
		Summer	Winter	Summer	Winter	Summer	Winter
1	0.27	400	400	0.1	0.1	-	-
2	1.31	370	390	0.4	0.4	0.5	0.5
3	1.26	330	350	0.5	0.4	1.0	0.9
4	2.79	270	310	1.5	1.2	2.5	2.1
5	1.56	140	220	1.5	0.9	4.0	3.0
6	0.86	70	170	1.6	0.7	5.6	3.7
Outlet	-	30	140	-	-		
Total	8.05			5.6	3.7		

When the supply water in which the nitrate -N concentration had been increased to 40 mg/l moved through the plot, there was a gradual reduction of the nitrate -N until at the outlet it had been reduced to about 1-4 mg/l.

At this time we can only theorize as to the cause of the variation in the removal rates, especially as to the greater reduction in the colder winter months with the diminished grass cover. The best explanation would seem to be that after the grass has died back and lodged, much of the plant matter is deposited in the water near the bottom of the ponds where the material is more rapidly decomposed thus resulting in a relatively large available carbon source.

As the grass decayed there were more open spaces on the water surface which might be expected to encourage an increase in algae growth thus accounting for some of the nitrate reduction by an increase in organic nitrogen in the algae plant cells. Algal determination made in February 1970 indicated that there was a decrease in the algal count as the water moved through the plot. The genera

and the estimated number of cells per milliter at several stations in the plot are listed in Table 6.

Tests for nitrite, ammonia and organic nitrogen indicate that, generally, there were small amounts of these N forms present however with the exception of some of the winter months there were no significant increase in these quantities as the water moved through the plot.

Table 6

Algae Count at Several Sampling Sites in Grass Plots - February 26, 1970

Sample	Genus	Cells/ml
Inlet	Diatom-Nitschia	2,500
	Diatom-Amphiprora	500
	Diatom-Diatoma	3,000
Check 2	Diatom-Diatoma	4,000
Check 4	Diatom-Diatoma	1,000
Outlet	Diatom-Diatoma	500

During the months in which there were increases in the total organic N at the outlet as compared to the inflow water these increased amounts were a relatively small portion of the total losses. There was no evidence that at any stage of the study there was a recycling of the lost nitrogen. This would suggest that denitrification with its resultant loss of nitrogen gas accounts for most of the nitrates removed. The concentration of various forms of nitrogen at several dates during the study are listed in Table 7.

Dissolved Oxygen - The changes in the dissolved oxygen content of the water as it moved through the plot were inconsistent. Generally, during the warmer periods when there was a good cover of grass over the ponds there was a reduction of the dissolved oxygen. During short periods of time when the reduction was at its peak, the DO was reduced from an average of about 8 to about 1 mg/l. Normally the reduction was at a lesser rate, with the maximum removal about 60 percent of the total. After December when there was very little grass still standing in the ponds the reduction was negligible. There was a fair correlation between the percent removal of DO and nitrates during the warmer months. At other periods there was no obvious correlation between the two parameters. During the late winter and early spring months there was almost complete removal of the nitrates but there was no significant reduction in the measured DO content. This fact would appear to be a

Table 7 - Concentration of various nitrogen forms, temperature, pH and electrical conductivity at four locations in the plot

Date	Location	N-Form NO_3	NO_2 mg/l	NH_3	Org.N	Temp. °C	pH	EC mmhos
First Period								
8-14-68	Inlet	8.5	.02	.35	-	25.3	8.3	1.4
"	Check #2	9.6	.90	.03	-	25.0	8.3	1.35
"	Check #4	2.2	.05	.01	-	24.5	8.0	1.3
"	Outlet	.6	.01	.3	-	27.0	8.2	1.7
9-11-68	Inlet	14.4	.03	.5	-	26.0	8.1	1.3
"	Check #2	9.7	.5	.5	-	24.0	8.1	1.1
"	Check #4	.2	0	.02	-	24.0	8.2	1.5
"	Outlet	.2	0	.02	-	27.0	8.0	1.0
11-1-68	Inlet	12.1	-	-	6.6	17.0	7.8	2.1
"	Check #2	9.5	-	-	8.3	15.0	7.8	2.0
"	Check #4	3.4	-	-	5.6	15.0	8.1	1.8
"	Outlet	1.1	-	-	4.3	14.5	7.4	1.3
2-28-69	Inlet	38.6	-	4.76	1.68	11.5	8.3	1.9
"	Check #2	29.5	-	.68	2.26	10.5	7.9	2.0
"	Check #4	.2	-	.68	5.34	13.0	7.6	1.9
"	Outlet	.2	-	4.76	6.72	13.0	7.6	1.7
Second Period								
8-29-69	Inlet	18.0	2.8	-	1.0*	23.0	8.0	1.6
"	Check #2	8.0	5.6	-	1.7*	18.0	7.8	1.4
"	Check #4	.8	0	-	2.0*	18.0	7.4	1.4
"	Outlet	.8		-	2.3*	18.0	7.8	1.5
9-12-69	Inlet	15.0	.8	.08	.80	20.0	7.6	1.4
"	Check #2	19.3	1.8	00	.64	19.5	7.8	1.4
"	Check #4	.5	.1	00	.70	19.5	7.9	1.4
"	Outlet	.5	.1	00	1.27	20.0	8.0	1.4
10-9-69	Inlet	11.0	1.1	.21	.85	19.0	7.6	.5
"	Check #2	9.1	.5	.05	.57	17.0	7.0	.5
"	Check #4	3.4	.9	.06	.88	16.0	6.9	.5
"	Outlet	1.0	.6	.16	.67	19.0	7.0	.5

* Total Organic N + NH_3

contradiction of the requirement of an anaerobic condition before the denitrification process takes place. At this point we can only postulate that the reaction takes place in local areas near the ground or the stem surface of the plants where there are anaerobic conditions but our sampling techniques were not sufficiently refined to detect these conditions.

Temperature - The temperature of the supply water varied from a maximum of 28°C in the summer to a minimum of 8°C in December and January. The reduction in the removal rate of the nitrates correlated reasonably well with the decrease in the temperature of the water in the early winter months of November and December. However, although there was no significant increase in the water temperature in January there was a decided increase in the nitrate removal rate.

Although not verified it may be that as the grass decayed, the decomposition products provided a readily available energy source that outweighed cool temperature effects. Regardless of the cause almost complete removal of nitrate was obtained with temperatures down to 8°C.

Percolating Water Studies - In August 1969 two sets of small porous ceramic cups were installed in the soil at locations near the inlets of checks 2 and 6. These cups were placed at 12 inch depth increments from 6 to 54 inches to get a nitrate concentration profile of the percolating water as it passed downward through the soil. Samples of the soil solution were collected from these depths by applying suction to the instruments. All the extracts collected were analyzed for nitrates, electrical conductivity and pH. For some extracts nitrite, ammonia and total organic N were determined.

The results of these tests indicated that there was a rapid reduction of the nitrates as the water moves into the soil. Most of the reduction took place before the water reached the 6 inch depth. These results are similar to the findings of Mikkelson, et al (11) in their studies of flooded soils. They found that there is only a thin layer of soil, not more than ¼ of an inch where oxygen is present. Below this, there is a reduction layer which changes the nitrate -N by biological reduction to N gas which escapes into the air.

The NO_3 analyses of samples taken from the various depths are listed in Table 8. These data indicate that in most instances maximum reduction had been reached at the 6-inch depth and after this depth there was very little change. The nitrate -N concentrations of most of the analyses were under 1 mg/l NO_3-N. With a few exceptions all of the analyses were less than 2 mg/l NO_3-N. These values would meet the nitrogen standards established for the discharge of agricultural waste water into the Delta.

Table 8

The Nitrate -N Concentration of the Soil Extract
From Several Depths Below the Grass Plot

Date	Surface	Depth 6"	18"	30"	42"	54"
	Milligrams per Liter - NO_3-N					
7/09/69		0.5	0.6	0.4	0.3	0.3
8/07/69		0.4	0.5	0.5	0.4	0.4
8/15/69	11.1	1.7	1.6	0.6	0.6	1.6
8/19/69		0.5	0.6	-	0.5	0.6
8/27/69	7.9	1.7	2.1	2.8	1.4	2.2
9/05/69	9.0	1.1	-	-	0.9	1.6
9/17/69	2.5	0.3	0.9	0.9	1.3	1.8
9/24/69	8.4	0.4	0.9	1.1	0.9	1.1
9/30/69	11.1	-	1.0	0.9	1.4	1.2
10/08/69	3.4	1.4	0.8	0.9	1.1	0.9
10/20/69	14.5	0.7	0.6	0.7	0.7	0.7
10/30/69	3.4	-	0.7	1.7	0.9	2.8
11/05/69	12.2	4.5	2.5	1.0	1.4	1.2
11/12/69	15.8	1.8	1.4	1.1	1.1	1.1
11/19/69	13.5	-	1.1	0.3	0.8	0.2
11/26/69	7.9	0.8	0.6	1.3	0.4	0.6
12/03/69	11.2	0.9	0.8	0.8	0.6	0.6
12/10/69	-	1.1	1.0	1.1	1.7	1.3
12/17/69		0.7	0.6	0.5	-	1.4
12/23/69		0.8	1.4	0.9	0.8	1.1
1/02/70		0.4	0.4	0.4	0.7	1.1
1/07/70	17.8	0.7	0.6	0.7	1.0	1.7
1/15/70		2.3	1.7	1.1	1.2	0.8
1/21/70		0.9	0.6	0.8	1.2	1.5
1/28/70	33.9	1.1	0.8	0.8	0.9	1.8
2/05/70		2.5	2.1	1.4	1.3	1.9
2/11/70		0.9	0.8	0.9	1.1	1.5
2/18/70		1.4	1.8	1.2	1.3	1.8
3/03/70		1.1	0.9	1.0	0.8	1.4

There were no drains installed under these plots, therefore, the effect of moving the water out of the area on the nitrate concentrations could not be measured. This type of measurement would be essential before definite recommendations could be made on this system. A system with drain tiles installed should be set up to determine if there is a continuous removal of the nitrates to permissible levels from the percolating water where there are established drains. Any drains installed should be "under designed" or so constructed that the drains are submerged to maintain continuous anaerobic conditions.

A mass nitrogen balance for the grass plot could be calculated employing the following equations:

(a) $N_i = N_o$

Where N_i = nitrogen in (pounds)

N_o = nitrogen out (pounds)

(b) $N_i = C_n Q_i k + R_i$

Where C_n = nitrogen concentration of inflow (mg/l)

Q_i = volume of flow (Ac. Ft.)

k = conversion factor to change units to pounds

R_i = N released from immobilized form (pounds)

(c) $N_o = D_s + D_p + P_d + I + O$

Where D_s = N denitrified in water - loss to air

D_p = N denitrified by plant decay - loss to air

P_d = N loss by deep percolation

I = N immobilized in organic forms

O = N lost in discharge outflow

At this time we do not have enough data to separate that portion of the nitrogen lost by denitrification and that lost by immobilization in organic forms. However, it is of interest to note the amount removed from the system by these combined processes. The calculations were based on the average values of the various parameters for a 24 hour period. The values used are listed in Table 9.

Table 9

Quantity of Surface Flow, NO_3-N Concentration and Deep Percolation in the Grass Plot for an Average 24-hour Period

Location	Flow A.F./day	Concentration NO_3-N, mg/l	Deep Percolation (1) A.F./day
Inlet	1.8	16	
Check #1	1.68	15	.11
Check #2	1.50	13	.16
Check #3	1.28	10	.19
Check #4	.80	5	.42
Check #5	.54	3	.23
Check #6	.38	2	.14
Outlet	.38	1	

(1) Deep percolation = flow loss minus evapotranspiration.

(b) $N_i = C_n Q_i k + R_i$

Where $C_n = 70$ ppm $NO_3 = 16$ ppm N

$Q_i = 1.8$ a.f.

$k = 2.72$

$R_i = 0.2$ lbs. - ave. daily N release from decomposition of plant material

$= 16 \times 1.8 \times 2.72 + .2 = 78.5$ pounds

(a) $N_o = N_i$

$N_o = 78.5$ pounds

(c) $N_o = D_s + D_p + P_d + I + 0$

$D_s + D_p + I = N_o - (P_d + 0)$

$P_d = C_{nd} Q_d k$

Where C_{nd} = N concentration of deep pecolation

Q_d = Quantity of deep percolation

P_d Check # 1 = $15 \times .11 \times 2.72$

= 4.5 pounds

Check # 2 = $13 \times .16 \times 2.72$

= 5.7 pounds

Check # 3 = $10 \times .19 \times 2.72$

= 5.2 pounds

Check # 4 = $5 \times .42 \times 2.72$

= 5.7 pounds

Check # 5 = $3 \times .23 \times 2.72$

= 1.9 pounds

Check # 6 = $2 \times .14 \times 2.72$

= .8 pounds

P_d = 23.7 pounds

$0 = 1 \times .38 \times 2.72$

= 1.0 pounds

$D_s + D_p + I = 78.5 - (23.7 + 1.0)$

= 53.8 pounds per day

The 53.8 pounds per day calculated here is that amount removed from the surface water. In addition to these losses, the studies indicate that the greater portion of the nitrogen in the water that percolates into the soil is also removed by denitrification. If time permits later studies will be designed to delineate that portion removed by each of the parameters; denitrification in the water, denitrification by plant decay and immobilization in an organic form.

A water balance can also be calculated for a system such as the grass plot using the formula:

$Q_i = Q_p + Q_e + Q_c + Q_o$

Where Q_i = total inflow (A.F.)

Q_p = deep percolation (A.F.)

Q_e = surface evaporation losses (A.F.)

Q_c = consumptive use (A.F.)

Q_o = surface outflow (A.F.)

In the shallow grass plot investigations all of the items except Q_p can be measured or calculated, therefore, if we want to solve for this factor for an average 24-hour period, the formula becomes:

$$Q_p = Q_i - (Q_e + Q_c + Q_o)$$

Where Q_i = 1.90 A.F./day
Q_e = .1 A.F./day
Q_c = .07 A.F./day
Q_o = .38 A.F./day

$$Q_p = 1.80 - (.1 + .07 + .38)$$
$$= 1.25 \text{ A.F./day}$$

SECTION VI

COST ANALYSES

Preliminary cost analyses were prepared of the two methods studied in this investigation to gain some concept of the cost of these methods in comparison to those studied in other phases of the program. The requirements were based on data obtained from the plot study and may be subject to revision upon more complete investigation.

The reconaissance design and cost estimates were prepared by the Bureau of Reclamation Regional Engineer's office. The values listed include design, construction, materials, contingencies and all indirect costs. The land values were based upon the costs of unimproved, native pastures within or near the Grasslands area.

The determinations of the costs of treatment by the two systems were based on the premise that the ultimate maximum drainage outflow from the San Luis Service Area had been reached and all treatment facilities were in operation. The maximum daily flow which the systems must treat will be 300 cubic feet per second and the total annual output will be about 155,000 acre feet. It is estimated that this maximum flow will be reached about thirty years after the start of operations. In actual practice, it may prove more economical to construct the facilities in stages as the drainage flows builds to maximum.

The land requirements for the treatment systems were based on criteria derived from the deep pond and grass plot studies. The deep pond system required approximately .09 acres to remove the nitrogen from .16 acre feet of drain water per day. This would be equivalent to 337 acres to treat the ultimate maximum drain flow of 300 cubic feet per second. As the nitrogen concentration of the water used in this study was only about 50 percent of the 21 mg/l projected to be in the San Luis Drain water, the pond area requirement was increased to 645 acres to make the costs equivalent to actual conditions. An additional 20 percent or 125 acres, was added to the land requirements for ditches, levees, roads and working areas. The total area requirement for this method would be approximately 800 acres. The shallow ponds required approximately 5.6 acres to treat 1.67 acre feet. This would be equivalent to about 2,080 acres required to treat the maximum flow of 300 cubic feet per second. Assuming an additional 20 percent of this area would be required for supplemental land uses, the total land requirement for the grass plots method will be approximately 2,500 acres.

Additional criteria used to estimate the costs of the two systems were as follows:

1. All costs were based upon January 1970 dollar values.

2. Capital and land costs amortized over 50 year period at 5% interest.

3. Capital costs include an engineering and contingency factor of approximately 56 percent.

4. All lands were purchased at start of the project at $500 per acre.

5. Electric power costs were calculated at 1¢/KWH.

6. Replacement costs were calculated on all material items on a sinking fund basis over a 50 year period at 5 1/8 percent interest.

7. Post treatment for algae removal would be required.

8. Based on costs of rice production as modified to fit specialized requirements.

9. Costs per acre foot treated were determined by dividing the total annual costs by the projected ultimate annual flow.

Based on the above criteria it was estimated that the deep pond denitrification would cost approximately $14.00 per acre foot or $43.00 per million gallons. The shallow grass pond method would cost about $6.50 per acre foot or $20.00 per million gallons. Lists of the various cost items appear in Tables 10 and 11. If it is determined at a later date that post treatment of the water for algae removal is not necessary the cost can be reduced by approximately $2.00 per acre foot or $6.00 per million gallons. Also if the operation of the systems is found to be compatible with the proposed use of Kesterson Reservoir additional savings in land acquisition and preparation costs may be realized.

Schematic layouts of portions of the systems are presented in Figures 6 and 7.

Table 10

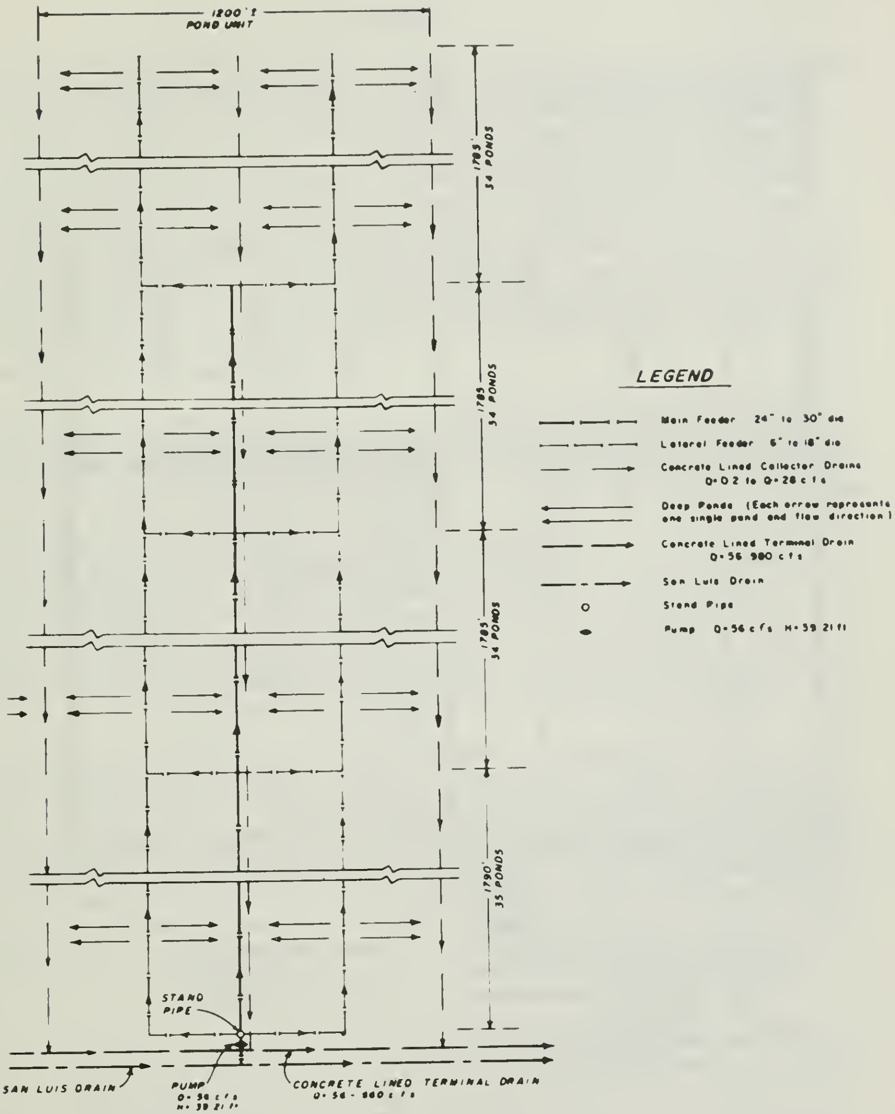
Estimated Cost for Removal of Nitrogen by Deep Pond Method

Number	Item	Cost
	Capital Costs	
	Nitrogen Removal	
1	Materials, Installations, Contingencies and Engineering	$22,800,000
2	Land Costs (800 acres @ $500/acre)	$ 400,000
	Subtotal	$23,200,000
	Post Treatment	
3	Algae Separation Facilities	$ 5,370,000
	Total Capital Costs	$28,570,000
	Annual Costs	
4	Ammortization of Capital Costs (50 yrs. @ 5%)	
	Nitrogen Removal	$ 1,270,000
	Algae Separation	$ 290,000
5	Replacement Costs (Sinking Fund @ 5-1/8% Interest)	$ 10,000
6	Operation, Maintenance and Administration	$ 200,000
7	Power Costs @ 1¢/KWH	$ 30,000
8	Material Costs (Barley Straw @ $15.50/ton)	$ 400,000
	Total	$ 2,200,000
	Cost per acre foot	$ 14.00
	Cost per million gallon	$ 43.00

Table 11

Estimated Costs for Removal of Nitrogen by Shallow Grass Plot Method

Number	Item	Cost
	Capital Costs	
	Nitrogen Removal	
1	Materials, Installations, Contingencies and Engineering	$ 7,240,000
2	Land Costs (2,500 acres @ $500/acre)	$ 1,250,000
	Subtotal	$ 8,490,000
	Post Treatment	
3	Algae Separation Facilities	$ 5,370,000
	Total Capital Cost	$ 13,860,000
	Annual Costs	
4	Ammortization of Capital Cost	
	Nitrogen Removal	$ 470,000
	Algae Separation	$ 290,000
5	Replacement Costs (Sinking Fund @ 5-1/8% Interest)	$ 10,000
6	Operation, Maintenance and Administration	$ 200,000
7	Power Costs @ 1¢/KWH	$ 30,000
	Total	$ 1,000,000
	Cost per acre foot	$ 6.50
	Cost per million gallons	$ 20.00



TYPICAL 1200' UNIT

FIGURE 6 — DEEP TRENCH NITRATE REDUCTION PONDS

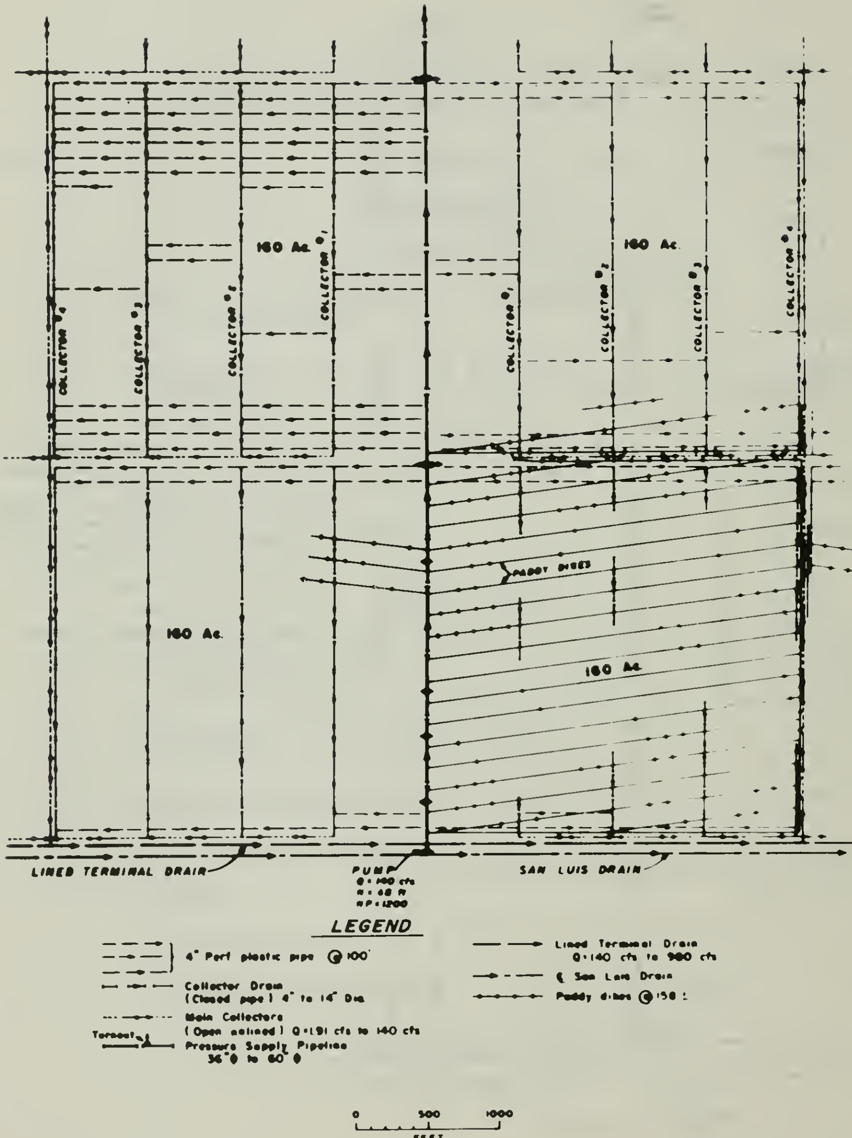


FIGURE 7 - SHALLOW NITRATE REDUCTION POND

TYPICAL SQ. MILE SECTION

SECTION VII

Discussion

These investigations were initiated as empirical studies to determine if denitrification could be induced by utilizing facilities somewhat similar to the San Luis Drain and the Kesterson Reservoir and using agricultural waste products or plants grown in place as the organic carbon source. When it was determined that it was possible to reduce the nitrate concentration by these means, the investigation was extended and refined to more precisely define parameters such as denitrification rates, optimum operating conditions, design criteria and costs. Because of the problems inherent in quantifying data from a relatively large field-size study the results were not always conclusive. However, although the many ramifications of the processes could not always be explained, it was evident that substantial percentages of the nitrates can be removed by these methods.

Air pollution control regulations in Fresno County (12) designed to promote environmental enhancement place restrictions on burning of stubble. These regulations will undoubtedly become more restrictive with time and will force growers to find other means to dispose of their straw. The use of the straw in a denitrification process would serve as one means of disposal. Cost of the straw to the project should be no more than baling, transportation expenses, and residue removal after oxidation. When the estimated peak drainage flow of 300 cubic feet per second is reached the daily straw requirement would be approximately 100 tons per day. The ultimate annual requirement for the estimated 155,000 acre-feet per year outflow will be about 26,000 tons. This would be equivalent to the straw yield from approximately 13,000 acres of grain.

Denitrification by the grass plot method or variation of this method shows considerable promise. Although the lack of suitable controls prevented precise evaluations of all causes and effects in the system, the empirical results indicate that the denitrification process will take place under the conditions studied. In the simple system in which water flowed across a grass covered field, it was demonstrated that the nitrate concentration during part of the year can be reduced to less than 2 mg/l nitrate -N. This level would meet the minimum standards for discharge into the Delta. At other times it would be necessary to store and recycle the water or treat the effluent with a more precisely controlled method.

The investigations indicated that water could be treated in shallow grass plots at the rate of .15 cubic feet per second per acre. At this rate approximately 2,000 acres of ponds would be required to service the 300 cubic feet per second of ultimate peak flow in the San Luis Drain or approximately 6,000 acres to treat an outflow of 1,000 cubic feet per second, the projected ultimate drainage outflow from the San Joaquin Valley. These estimates were based on the

assumption that the experimental criteria derived from the test site can be extrapolated to a large scale system. In addition to the land required for the ponds additional areas will be required for ditches, roads and other service areas. The total land requirement to treat the flow from the San Luis Service Area would be approximately 2,500 acres.

Several variations of this plan might be implemented. At this time the most feasible method would seem to be to incorporate the shallow ponds into the Kesterson Reservoir area. This would permit many of the facilities and structures, already designed into the Reservoir to be used in the denitrification plan and yet not essentially change the main purposes for which the Reservoir was designed. Some supplemental facilities would have to be installed such as additional contour checks, flow control structures, ditches, and pumps. A layout of a typical section of ponds is shown in Figure 7.

If no satisfactory arrangement can be worked out to use the Kesterson facilities, it would be necessary to purchase additional lands for the denitrification. The most logical location for these would be in the Grasslands.

A variation of this plan would be a system in which denitrification of surface flows was supplemented by denitrification in percolating waters through the soils. In this plan a drain system would be installed beneath the ponds at a depth near 42 inches. These drains would be designed so that they would be submerged at all times.

Infiltration would be encouraged and the percolating waters collected in the field drains and returned to main collector system. This plan would require additional construction expenses for the drain installations, however, the present studies indicate that this method gives more consistent and complete nitrate removal than any other type investigated.

Another alternative of this plan would be to reach an agreement with the Grasslands Soil Conservation District to cooperate in their "Master Plan for Land and Water Use in the Grasslands of Western Merced County California" (13). This agency has authorized a series of studies to investigate the feasibility of a program to enhance the wildlife program of the area. The major objectives of this plan are to import sufficient water of reasonable quality to provide a year round program to assist in developing a grazing plan consistent with wildlife and livestock and improve the migratory waterfowl habitat vital to the maintenance of the Pacific Flyway.

Studies have indicated that the area could use approximately 400,000 acre-feet of water during the peak use months of June, July and August (14). The Grassland Soil Conservation District presently

has a contract with the water districts of the area to the affect that it will accept drainage water with total dissolved solids up to 3,000 parts per million (14). If the waters in the San Luis and master drain could meet these standards it might be advantageous to seek an agreement with the Grasslands to deliver these waters to that area. The nitrates in the water moving through the native and pasture grasses on these lands should be reduced in essentially the same manner as in the grass plots study.

After the water has moved through these grasslands any runoff water could be collected into the Kesterson Reservoir. The northern (lower) boundary of the Grasslands Water District joins the southwest boundary of the Kesterson Reservoir, therefore, it would be relatively easy to collect the excess and presumably denitrified runoff water into Kesterson Reservoir.

At this point such a plan is purely speculative and may be in conflict with some of the purposes of the drainage program, however, it would appear to have sufficient merit to warrant further investigation whenever all parties have firmed up their plans.

SECTION VIII

ACKNOWLEDGEMENTS

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SECTION IX

REFERENCES

(1) Johnston, W. R., Ittihadieh, F., Daum, Richard M., Pillsbury, Arthur F., "Nitrogen and Phosphorous in Tile Drainage Effluent," Soil Sc. Soc. Ameri. Pro., Vol. 29, p. 287-289, 1965.

(2) State of California, Department of Water Resources, "San Joaquin Valley Drainage Investigations, San Joaquin Master Drain," preliminary edition, Bulletin No. 127, Jan. 1965.

(3) Goldman, Joel C., Arthur, James F., Oswald, William J., Beck, Louis A. "Combined Nutrient Removal and Transport System for Tile Drainage from the San Joaquin Valley", Agricultural Waste Water Treatment Center, Firebaugh, Calif., Dec. 1969.

(4) Nightingale, Harry, Personal Communication, ARS, U.S.D.A., Fresno, California, Sept. 1969.

(5) Cole, R. C., et al, "Soil Survey, The Los Banos Area, California", U.S.D.A., p. 58, 1952.

(6) Instruction Manual, Nitrate Ion Electrode Model 92-07, Orion Research Inc., Cambridge, Mass., 1967.

(7) "Standard Methods for the Examination of Water and Wastewater", American Public Health Association, Inc., New York, N.Y., 12th Ed. 1965.

(8) Reclamation Instructions, Release No. 577-1 U.S. Department of the Interior, Bureau of Reclamation, Office of Chief Engineer, Denver, Colorado, 1967.

(9) Connel, W. E., and Patrick, W. H., Reduction of Sulfate to Sulfide in Waterlogged Soils, Soil Sc. Soc. Amer. Pro. Vol. 33, 1969.

(10) State of California, Department of Water Resources, "Field Evaluation of Anaerobic Denitrification in Simulated Deep Ponds", Bulletin No. 174-3, May 1969.

(11) Mikkelson, D. S., Finfrock, D. C., Miller, M. D., "Rice Fertilization", California Agric. Exp. Sta. University of Calif., Davis, Leaflet 96, June 1958.

(12) Fresno County Air Pollution Control District, Rules and Regulations, Fresno, Calif., June 2, 1969.

(13) M & L Engineering "Master Plan for Land and Water Use in the Grasslands of Western Merced County, California,"Phase III, Los Banos, Calif., 1967.

(14) Dickey, G. L., "Master Plan for Land and Water Use in the Grasslands of Western Merced County, California", Phase I, U.S. Soil Conservation Service, Fresno, California, Unpublished Data.

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Three methods to remove nitrates from the agricultural drainage water from the San Luis Service Area were investigated. One method was a theoretical evaluation of nitrate removal by algae during the transport of the drainage water in the San Luis Canal or during storage in the Kesterson Reservoir. The other methods were designed to promote anaerobic bacterial denitrification in a continuous flow of drainage water. One method used barley straw and the other water grass grown in shallow ponds as the carbon energy source. The barley straw was placed in a trench about 10 feet deep and the nitrate removal rate determined under various flow and detention rates. The water grass was grown in ponds under a continuous flow of water of about 4 to 6 inches depth. Under optimum conditions both methods reduced the nitrate -N concentration of the drainage water from a maximum of about 30 mg/l to less than 2 mg/l. The cost of nitrogen removal by the shallow grass plot systems, the most economical and feasible method investigated, was estimated to be $6.50 per acre foot or $20.00 per million gallons.

Abstractor John Williford | *Institution* U. S. Bureau of Reclamation

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